**DISSERTATION ON**

# MICROSURGICAL ANATOMY OF THE MIDDLE CEREBRAL ARTERY

**M.Ch., Degree Examination**

**Branch II - Neurosurgery**

**THE TAMILNADU Dr.M.G.R. MEDICAL UNIVERSITY**
**CHENNAI.**

**FEBRUARY - 2006**

# CERTIFICATE

This is to certify that the dissertation entitled **MICROSURGICAL ANATOMY OF THE MIDDLE CEREBRAL ARTERY** was done under our supervision and is the bonafide work of **Dr.P.Srinivasan**. It is submitted in partial fulfillment for the M.Ch. Neurosurgery Examination.


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# ACKNOWLEDGEMENT

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# AIM OF THE STUDY

To study the variations in microsurgical anatomy of the Middle cerebral artery in our population and to discuss its implication with respect to anatomical, pathophysiological and neurosurgical perspectives.

# INTRODUCTION

Microneurosurgery, has evolved, over the years with the better understanding of the normal anatomy and myriads of variations that occur in the miniature structures of the brain. Micro dissection of cadaver specimens is the base on which our knowledge of the intricate anatomy of the human brain is built.

Neurovascular anatomy of the brain, is the most complex of all and the variations encountered are as distinct as a finger print. Most neurovascular surgeons in the premicroscopic era, were handicapped with a poor knowledge of the minute vessels that supplied the vital regions of the brain. They were not able to explain the unexpected defecits patient suffered after apparently uneventful surgery.

The advent of microneurosurgery and the knowledge of the tiny perforating vessels and their arrangements along the base of the brain has made much awaited changes in the outcome of patients undergoing surgery in relation to neurovascular structures.

Middle cerebral artery is the largest and complex arterial system of the brain. Thorough knowledge of the microsurgical anatomy and the anatomical variations, are mandatory for the neurosurgeons to adopt the best possible technique to avoid disaster during surgery and to have good functional outcome in patients.

Various authors have studied, the MCA in detail and have explained the variations in their population. No large study of this nature has been done in our population, though few small Indian studies have been done. This study is done to improve the knowledge of the variations in micro surgical anatomy of the middle cerebral artery in our population.

# ABBREVIATIONS USED

| | | |
|---|---|---|
| IC | - | Internal Carotid Artery |
| IC OD | - | Internal Carotid Artery Outer Diameter |
| IC CSA | - | Internal Carotid Artery Cross Sectional Area |
| $A_1$ | - | Anterior Cerebral Artery First Segment |
| $A_1$ OD | - | Anterior Cerebral Artery First Segment outer diameter |
| $A_1$ CSA | - | Anterior Cerebral Artery First Segment Cross Sectional Area |
| $M_1$ | - | Middle Cerebral Artery First Segment |
| $M_1$OD | - | Middle Cerebral Artery First Segment Outer diameter |
| $M_1$ CSA | - | Middle Cerebral Artery First Segment Cross Sectional Area |
| MCAL | - | Middle Cerebral Artery First Segment Length |
| EBR | - | Early Branches |
| ACC MCA | - | Accessory Middle Cerebral Artery |
| MCA | - | Middle Cerebral Artery |
| ACA | - | Anterior Cerebral Artery |
| AChA | - | Anterior Choroidal Artery |
| PP | - | Proximal perforators |
| DP | - | Distal Perforators |
| FTPF | - | Frontal and Temporal Artery Perforators |
| LCTO | - | Largest cortical Tempro occipital artery |
| LCA | - | Largest cortical angular artery |
| PfA | - | Perforating Arteries |

# NORMAL MICROSURGICAL ANATOMY OF THE MIDDLE CEREBRAL ARTERY

The MCA is the largest and most complex of the cerebral arteries. Some of its branches are exposed in most operations in the supratentorial area, whether the approach is to the cerebral convexity, parasagittal region, or along the cranial base. In the past, surgical interest in the MCA has been directed at avoiding damage to its branches during operations within its territory, but micro-operative techniques have now made reconstruction of and bypass to the MCA an important method of preserving and restoring blood flow to the cerebrum.

The MCA arises as the larger of the two terminal branches of the internal carotid artery. The diameter of the MCA at its origin is roughly twice that of the anterior cerebral artery. Its origin is at the medial end of the sylvian fissure, lateral to the optic chiasm, inferior to the anterior perforated substance, and posterior to the division of the olfactory tract into the medial and lateral olfactory striae. From its origin, it courses laterally below the anterior perforated substance and parallel, but roughly one cm posterior, to the sphenoid ridge. As it passes below the anterior perforated substance, it gives rise to a series of perforating branches referred to as lenticulostriate arteries. It divides within the sylvian fissure and turns sharply posterosuperiorly at a curve, the genu, to reach the surface of the insula. At the periphery of the insula, the branches pass to the medial surface of the opercula of the frontal, temporal, and parietal lobes. Its branches pass around the opercula to reach the cortical surface

and supply most of the lateral surface and some of the basal surface of the cerebral hemisphere.

***Segments***

The MCA is divided into four segments: $M_l$ (sphenoidal), $M_2$ (insular), $M_3$ (opercular), and $M_4$ (cortical). The $M_1$ begins at the origin of the MCA and extends laterally within the depths of the sylvian fissure. It courses laterally, roughly parallel to and approximately one cm posterior to the sphenoid ridge in the sphenoidal compartment of the sylvian fissure. This segment terminates at the site of a 90-degree turn, the genu, located at the junction of the sphenoidal and operculoinsular compartments of the sylvian fissure. This bifurcation occurs proximal to the genu in most hemispheres. The small cortical branches arising from the main trunk proximal to the bifurcation are referred to as early branches.

The $M_2$ segment include the trunks that lie on and supply the insula. This segment begins at the genu where the MCA trunks passes over the limen insulae and terminates at the circular sulcus of the insula. The greatest branching of the MCA occur distal to the genu as these trunks cross the anterior part of the insula. The branches passing to the anterior cortical areas have a shorter path across the insula than those reaching the posterior cortical areas. The branches to the anterior frontal and anterior temporal areas cross only the anterior part of the insula, but the branches supplying the posterior cortical areas course in a nearly parallel but diverging path across the length of the insula. The frontal branches cross only the short gyri before leaving the insular

surface, whereas the branches supplying the posterior parietal or angular regions pass across the short gyri, the central sulcus, and the long gyri of the insula before leaving the insular surface.

The $M_3$ segment begins at the circular sulcus of the insula and ends at the surface of the sylvian fissure. The branches forming the $M_3$ segment closely adhere to and course over the surface of the frontoparietal and temporal opercula to reach the superficial part of the sylvian fissure. The branches directed to the brain above the sylvian fissure undergo two 180-degree turns. The first turn is located at the circular sulcus, where the vessels coursing upward over the insular surface turn 180 degrees and pass downward over the medial surface of the frontoparietal operculum. The second 180-degree turn is located at the external surface of the sylvian fissure, where the branches complete their passage around the inferior margin of the frontoparietal operculum and turn in a superior direction on the lateral surface of the frontal and parietal lobes.

The arteries supplying the cortical areas below the sylvian fissure pursue a less tortuous course. These branches, on reaching the circular sulcus, run along its inferior circumference before turning upward and laterally on the medial surface of the temporal operculum, thus producing a less acute change in course at the inferior margin of the circular sulcus. On reaching the external surface of the sylvian fissure, these branches are directed downward and backward on the surface of the temporal lobe.

The $M_4$ is composed of the branches to the lateral convexity. They begin at the surface of the sylvian fissure and extend over the cortical surface of the cerebral hemisphere. The more anterior branches turn sharply upward or downward after leaving the sylvian fissure. The intermediate branches follow a gradual posterior incline away from the fissure, and the posterior branches pass backward in nearly the same direction as the long axis of the fissure.

***Perforating Branches***

The perforating branches of the MCA enter the anterior perforated substance and are called the lenticulostriate arteries. There is an average of 10 lenticulostriate arteries per hemisphere. Lenticulostriate branches arise from the prebifurcation part in every case and from the postbifurcation part in half of the hemispheres. The earlier the bifurcation, the greater the number of postbifurcation branches. The lenticulostriate arteries are divided into medial, intermediate, and lateral groups, each of which has a unique origin, composition, morphology, and characteristic distribution in the anterior perforated substance. The medial group is the least constant of the three groups and is present in only half of the hemispheres. When present, it consists of one to five branches that arise on the medial part of the $M_1$ segment near the carotid bifurcation or an early branch, and pursue a relatively direct course to enter the anterior perforated substance just lateral to the branches from Internal Carotid Artery.

The lateral and intermediate groups of lenticulostriate arteries pass through the anterior perforated substance, putamen and arch medially and

posteriorly to supply almost the entire anterior-to-posterior length of the upper part of the internal capsule and the body and head of the caudate nucleus. The medial lenticulostriate arteries irrigate the area medial to and below that supplied by the lateral and intermediate lenticulostriate arteries; this area includes the lateral part of the globus pallidus, the superior part of the anterior limb of the internal capsule, and the anterosuperior part of the head of the caudate nucleus.

***Cortical Distribution***

The cortical territory supplied by the MCA includes the majority of the lateral surface of the hemisphere, all of the insular and opercular surfaces, the lateral part of the orbital surface of the frontal lobe, the temporal pole, and the lateral part of the inferior surface of the temporal lobe. The MCA territory does not reach the occipital or frontal poles or the upper margin of the hemisphere, but it does extend around the lower margin of the cerebral hemisphere onto the inferior surfaces of the frontal and temporal lobes.

The narrow peripheral strip on the lateral surface of the cerebral hemisphere, supplied by the ACA and PCA rather than the MCA, extends along the entire length of the superior margin of the hemisphere from the frontal to the occipital pole. It is broadest in the superior frontal region and narrowest in the superior parietal area. This strip continues around the occipital pole and onto the posterior part of the lateral surface of the temporal lobe and narrows and disappears anteriorly on the temporal lobe where the branches of the MCA

extend around the lower border of the hemisphere onto the inferior surface of the temporal lobe and the orbital surface of the frontal lobe.

The cortical area supplied by the MCA is divided into 12 areas

1. ***Orbitofrontal area.*** The orbital portion of the middle and inferior frontal gyri and the inferior part of the pars orbitalis.

2. ***Prefrontal area.*** The superior part of the pars orbitalis, the pars triangularis, the anterior part of the pars opercularis, and most of the middle frontal gyrus.

3. ***Precentral area.*** The posterior part of the pars opercularis and the middle frontal gyrus, and the inferior and middle portions of the precentral gyrus.

4. ***Central area.*** The superior part of the precentral gyrus and the inferior half of the postcentral gyrus.

5. ***Anterior parietal area.*** The superior part of the postcentral gyrus, and frequently, the upper part of the central sulcus, the anterior part of the inferior parietal lobule, and the anteroinferior part of the superior parietal lobule.

6. ***Posterior parietal area***. The posterior part of the superior and inferior parietal lobules, including the supramarginal gyrus.

7. ***Angular area.*** The posterior part of the superior temporal gyrus, variable portions of the supramarginal and angular gyri, and the superior parts of the lateral occipital gyri (the artery to this area is considered the terminal branch of the MCA).

8. ***Temporo-occipital area.*** The posterior half of the superior temporal gyrus, the posterior extreme of the middle and inferior temporal gyri, and the inferior parts of the lateral occipital gyri.

9. ***Posterior temporal area.*** The middle and posterior part of the superior temporal gyrus, the posterior third of the middle temporal gyrus, and the posterior extreme of the inferior temporal gyrus.

10. ***Middle temporal area***. The superior temporal gyrus near the level of the pars triangularis and pars opercularis, the middle part of the middle temporal gyrus, and the middle and posterior part of the inferior temporal gyrus.

11. ***Anterior temporal area***. The anterior part of the superior, middle, and inferior temporal gyri.

12. ***Temporopolar area.*** The anterior pole of the superior, middle, and inferior temporal gyri.

***Branching Pattern***

The main trunk of the MCA divides in one of three ways: bifurcation into superior and inferior trunks; trifurcation into superior, middle, and inferior

trunks; or division into multiple (four or more) trunks. Most of the MCAs divide by bifurcation(80%), some by trifurcation(10%), and others by giving rise to multiple trunks. The distal division of the MCA also generally occurs in a series of bifurcations. The small arteries that arise proximal to the bifurcation or trifurcation and are distributed to the frontal or temporal pole are referred to as early branches.

The MCAs that bifurcate are divided into three groups, designated equal bifurcation, superior trunk dominant, and inferior trunk dominant, based on the diameter and the size of the cortical area of supply of their superior and inferior trunks. The equal bifurcation yields two trunks with nearly equal diameters and size of cortical area. The inferior trunk supplies the temporal, temporo-occipital, and angular areas, and the superior trunk supplies the frontal and parietal regions. The superior trunk usually supplies the orbitofrontal to the posterior parietal areas, and the inferior trunk usually supplies the angular to the temporopolar areas. The inferior trunk dominant type of bifurcation yields a larger inferior trunk that supplies the temporal and parietal lobes and a smaller superior trunk that supplies all or part of the frontal lobe. The maximal area perfused by the inferior trunk includes all of the territory between and including the precentral and temporopolar areas. The superior trunk dominant type of bifurcation yields a larger superior trunk that supplies the frontal and parietal regions and a smaller inferior trunk that supplies only the temporal lobe. The maximal area supplied by the dominant superior trunk includes the orbitofrontal to the temporo-occipital areas.

***Stem Arteries***

The stem arteries arise from the trunks and give rise to the individual cortical branches. They arise from the main trunk and the two or more trunks formed by a bifurcation, trifurcation, or division into multiple trunks. There is considerable variation in the number and size of the area supplied by the stem arteries. The most common pattern is made up of eight stem arteries per hemisphere.

The individual stem arteries give rise to one to five cortical arteries. The most common pattern is for one of the 12 cortical areas to be supplied by a stem artery supplying one or two adjacent areas. The cortical areas most commonly receiving a stem artery serving only that area are the temporo-occipital, angular, and central areas. Stem arteries supplying four or five of the cortical areas are most commonly directed to the area below the sylvian fissure.

***Cortical Arteries***

The cortical arteries arise from the stem arteries and supply the individual cortical areas. Generally, one, or less commonly, two cortical arteries (range, one to five) pass to each of the 12 cortical areas. The smallest cortical arteries arise at the anterior end of the sylvian fissure and the largest arteries arise at the posterior limits of the fissure. The cortical branches to the frontal, anterior temporal, and anterior parietal areas are smaller than those supplying the posterior parietal, posterior temporal, temporo-occipital, and angular areas. The smallest arteries supply the orbitofrontal and temporopolar areas, and the largest ones supply the temporo-occipital and the angular areas. There is an

inverse relationship between the size and number of arteries supplying a cortical area. The temporo-occipital area has the smallest number of arteries, but they are the largest in size, and the prefrontal area has the largest number of arteries, but they are smaller.

The temporopolar, temporo-occipital, angular, and anterior, middle, and posterior temporal arteries usually arise from the inferior trunk; the orbitofrontal, prefrontal, precentral, and central arteries usually arise from the superior trunk. The anterior and posterior parietal arteries have an origin evenly divided between the two trunks and usually arise from the dominant trunk.

### *Early Branches*

The cortical arteries arising from the main trunk proximal to the bifurcation or trifurcation are called early branches. The early branches are distributed to the frontal or temporal lobes. Nearly half of MCAs send early branches to the temporal lobe, but less than 10% give early branches to the frontal lobe. The temporal branches usually supply the temporopolar and anterior temporal areas. The frontal branches terminate in the orbitofrontal and prefrontal areas. A few MCAs will give rise to early branches to both the frontal and temporal areas.

### *Anomalies*

Anomalies of the MCA, consisting of either a duplicate or an accessory MCA, are infrequent and occur less often than anomalies of the other intracranial arteries. A duplicated MCA is a second artery that arises from the

internal carotid artery and an accessory MCA is one that arises from the anterior cerebral artery. Both the duplicate and accessory MCAs send branches to the cortical areas usually supplied by the MCA. The accessory MCAs usually arise from ACA, IC, AchA or PcomA. The accessory MCA arising from ACA is differentiated from a recurrent artery of Heubner by the fact that the recurrent artery, although arising from the same part of the anterior cerebral artery as an accessory MCA, enters the anterior perforated substance, but the accessory MCA, although sending branches to the anterior perforated substance, also courses lateral to this area and sends branches to cortical areas normally supplied by the MCA.

# REVIEW OF LITERATURE

- The advent of microsurgical techniques in cerebrovascular surgery has interested many like, Chater et al (1976), Grand et al (1980), Gibo et al (1981), Umnasky et al (1984), to do research on micro surgical anatomy of cerebral vasculature.

- Yasargil M.G. (1984)[2] states that in 70% of cases MCA was larger than ACA. The infromedial perforators of $M_1$ segment of MCA ranged from 2-15 in number. Yasargil has demonstrated fenestrated $M_1$ segment as a rare anomaly encountered.

- Gibo et al (1981) states that in bifurcating MCA 28% had superior trunk dominance, 32% had inferior trunk dominance, 18% had equal division. A.L.Rhoton has stated a similar incidence.

- A.L. Rhoton (1984)[1] has stated that the MCA outer diameter to be 3.5mm on average. There are 4-6 early branches per hemisphere, the size of each vessel varied depending on the cortical area supplied. The anteroinferior part of the limiting sulcus is devoid of large perforating vessels and it is the safe area to make insular cortical incision. A.L.. Rhoton has stated that the number of infromedial perforators varies from 1-21 in number per hemisphere.

- Umnasky et al states that M1 length was 15.7mm on an average. Of all the perforators of MCA 79% was from $M_1$, 15.3% was from secondary trunks and 5.7% was from early temporal and frontal branches.

- S. Balaji pai states that the MCA at the origin has an outer diameter varying from 2.5mm – 4.6 mm while yasargil states that it varied from 2.4 - 4.6 mm. S. Balaji Pai states that the average length of $M_1$ is 20mm. The number of infromedial perforators varies from 3-11 in number per hemisphere. On an average 4.5 stem arteries arose from superior trunk and 4 stem arteries arose from inferior trunk.

# MATERIALS & METHODS

- 30 fresh adult cadavers of both sexes were examined in the autopsy theatre of the Institute of forensic medicine, Madras Medical College and Government General Hospital, Chennai. between January 2004 - June 2005.

- Entire dissection was carried out under 4x magnification using Carl zeiss magnifying loupe.

- Standard verniar caliper with accuracy of 0.2 mm was used for measurements.

- Other instruments used are toothed forceps, needle, syringe, poster colour, cotton, scissors, 11 blade knife, curved and straight artery forceps.

- 5 mega pixel sony digital camera was used for taking photographs.

**DISSECTION**

During autopsy, of the skull vault is removed carefully and care is taken not to damage the dura. The dura in the frontal region is incised and 15ml of 20% formaldehyde is injected into the subdural space. After 10 minutes dura is opened transversely and the anterior limit of falx cerebri cut. The two frontal lobes are retracted slowly and carefully to expose and cut the optic nerves and ICAs at their entrance into cranial cavity.

Both the cerebral hemipheres are progressively lifted after cutting cranial nerves one by one at their exit. The brain stem and basilar artery are cut at the level of tentorial hiatus. The falx cerebri posterior attachment is cut to completely remove both cerebral hemispheres. The entire specimen is soaked in 10% formaldehyde solution for 10-15 mins.

- Further dissections are done under 4x magnification.
- The sylvian fissure is injected with 5ml saline to ease dissection while opening the sylvian fissure. The sylvian fissure is opened by standard microneurosurgical technique above the superficial sylvian vein.
- The ICA is traced to bifurcation then the MCA and its branches coursing over the insula, opercula and the cortical areas are carefully dissected.

- The ICA at its origin is tied and injected with red poster colour solution to make the vessel prominent and to ease the dissection of perforators.

- The Outer diameter of the ICA just before division, and the outer diameters of ACA and MCA just after their origin are noted.

- The tiny branches of the $M_1$ Segment of MCA carefully dissected to expose the superolateral early branches and infromedial basal perforating vessels.

- Number of perforators and their distribution along the middle cerebral arteries are taken note.

- Number of early branches and their branching taken note of.

- The branching pattern of MCA into trunks is noted.

- The dissection is further carried along each trunk dividing into stem arteries and their course over the insula, opcercula and cerebral cortex are taken note of.

- The perforators of each of these vessels to the insular cortex are taken note of.

- The largest of the cortical vessel in noted.

- Finally the dissected MCA is photographed.

# OBSERVATIONS

The following observations and measurements are made meticulously and are recorded on a chart.

1. Middle Cerebral artery outer diameter (just distal to division)
2. Middle Cerebral Artery Length
3. Anterior Cerebral artery outer diameter (Just distal to division)
4. Internal Cerebral artery outer diameter (Just proximal to division)
5. Early Branches (Cortical vessels arising from M1)
6. Accessory MCA (May be from ACA, ICA, Anterior choroidal artery)
7. Perforators

    1. $M_1$ Perforators

        Proximal

        Distal

    2. $M_2$ Perforators

    3. From proximal frontal & temporal arteries.

8. Division of Middle cerebral artery.

    - Bifuraction
    - Trifurcation
    - Multiple Branches

9. Dominance of the trunk.

10. Origin of each cortical vessel from the trunk.

11. Largest cortical vessel.

# FIGURES

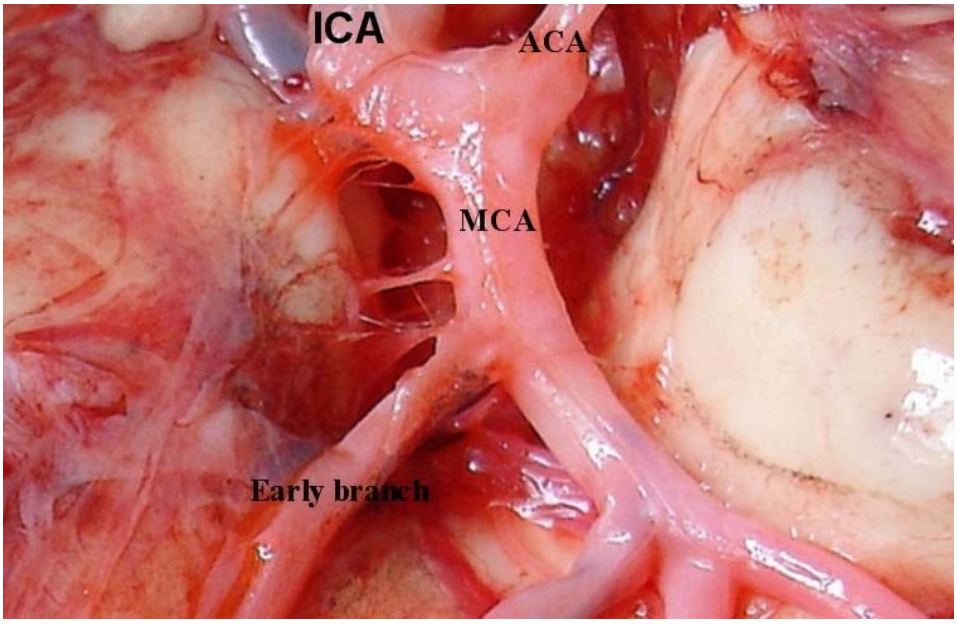



**Fig.1 : MCA Showing Early Branch**

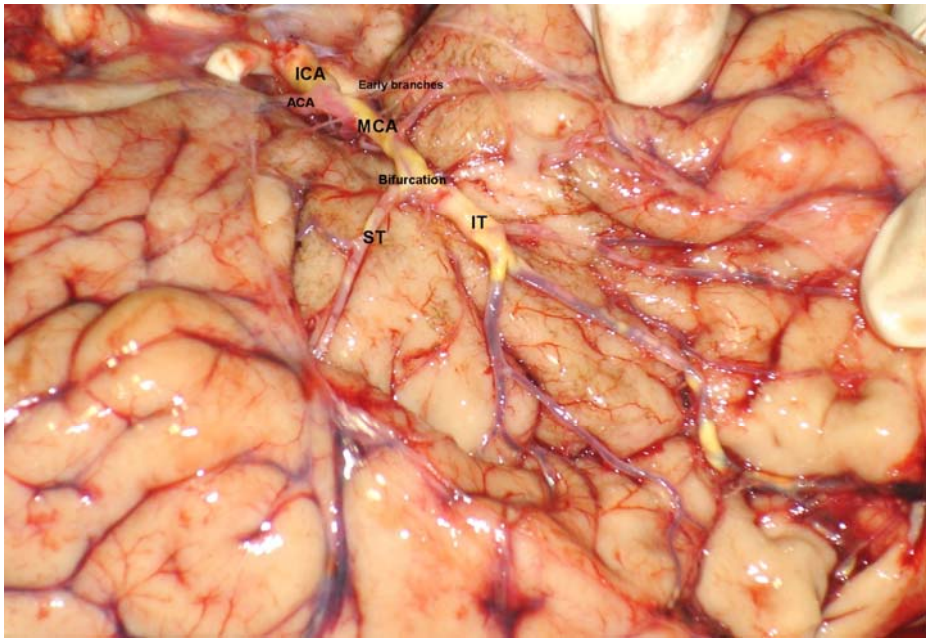



**Fig.2 : Bifurcating MCA**

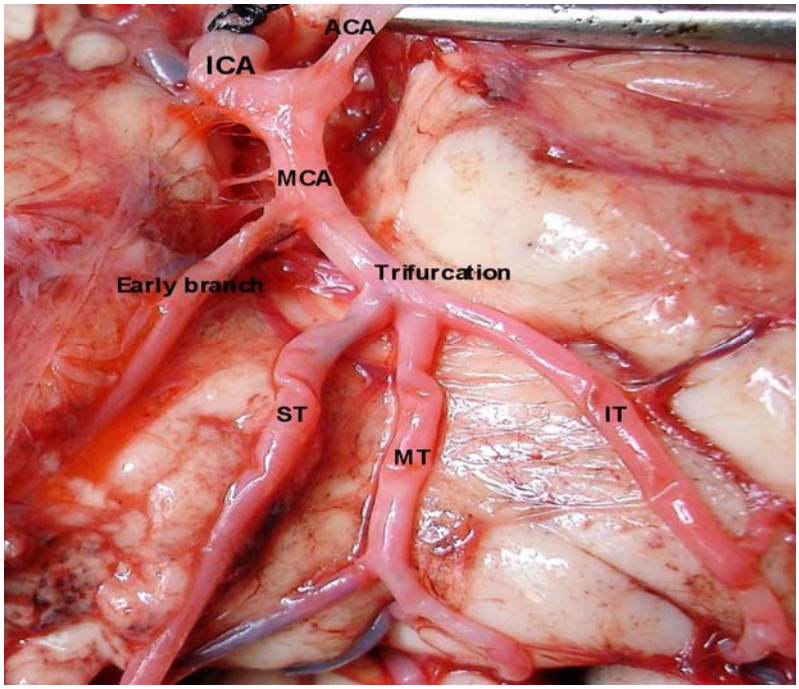



**Fig.3 : Trifurcating MCA**

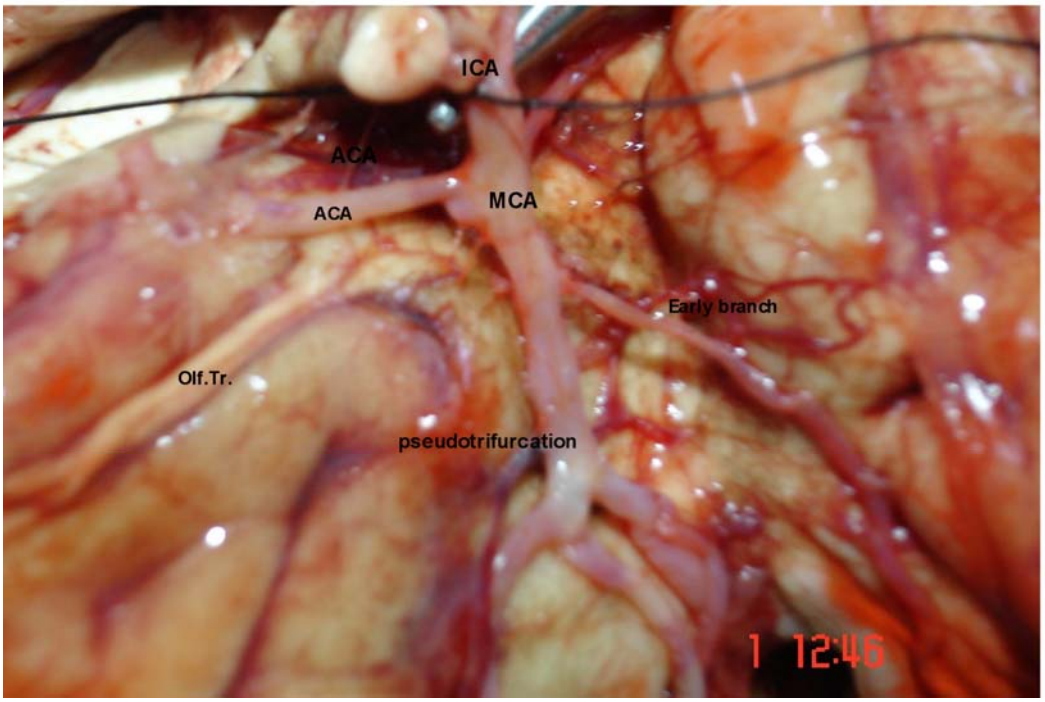



**Fig.4 : Pseudo Trifurcating MCA**

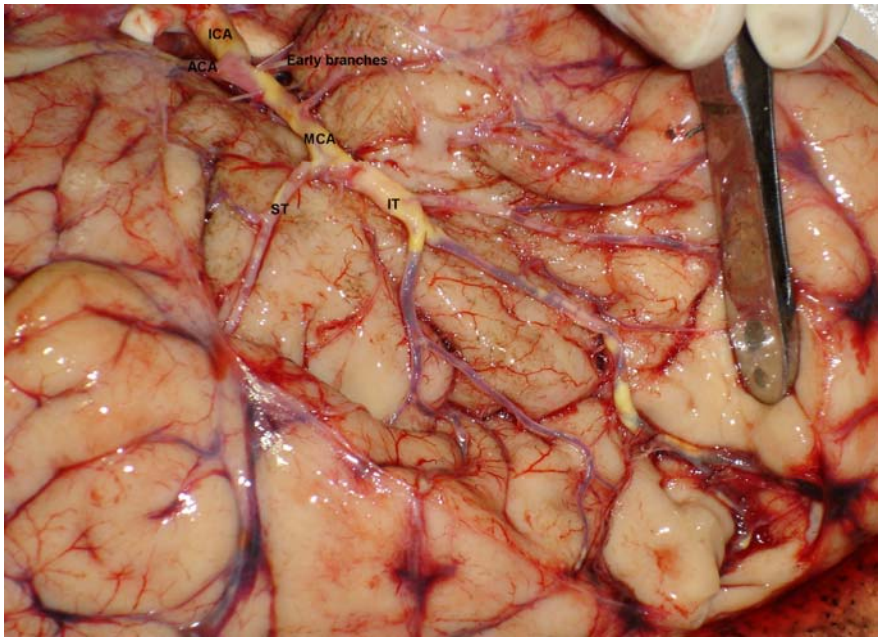



**Fig.5 : Branching Over Insular Cortex**

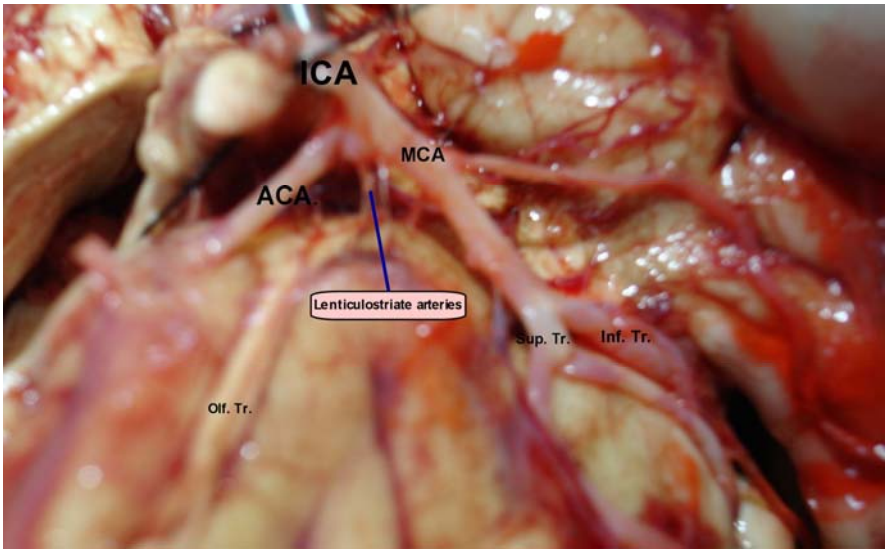



**Fig.6 : Lenticulostriate Arteries from $M_1$**

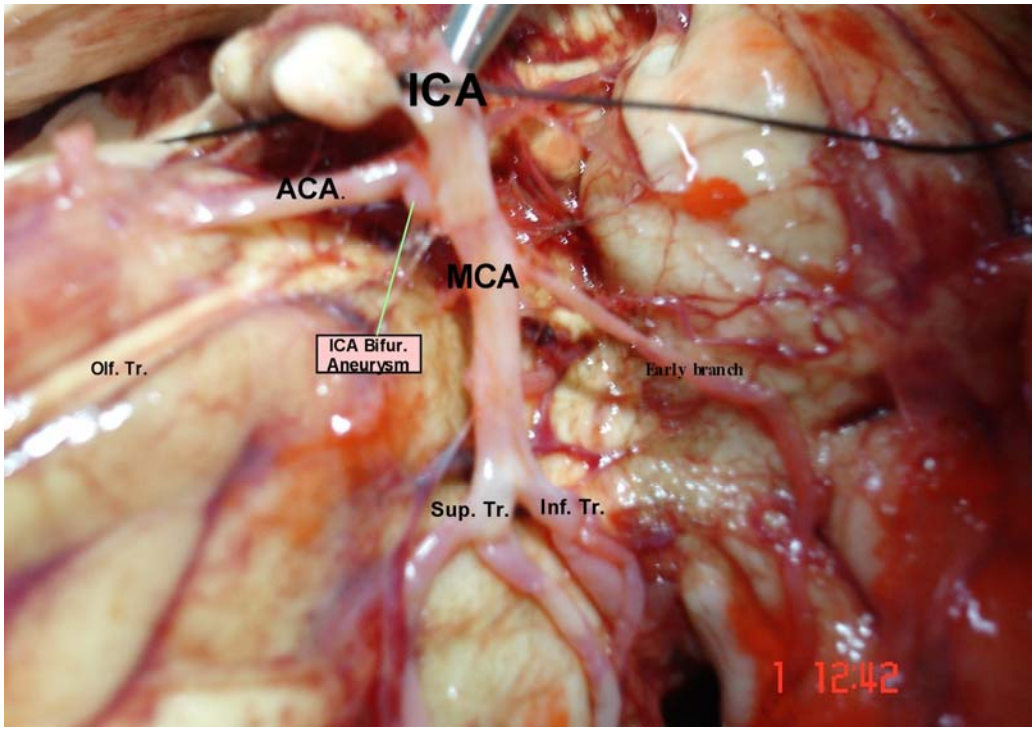



**Fig.7 : Incidental Aneurysm**

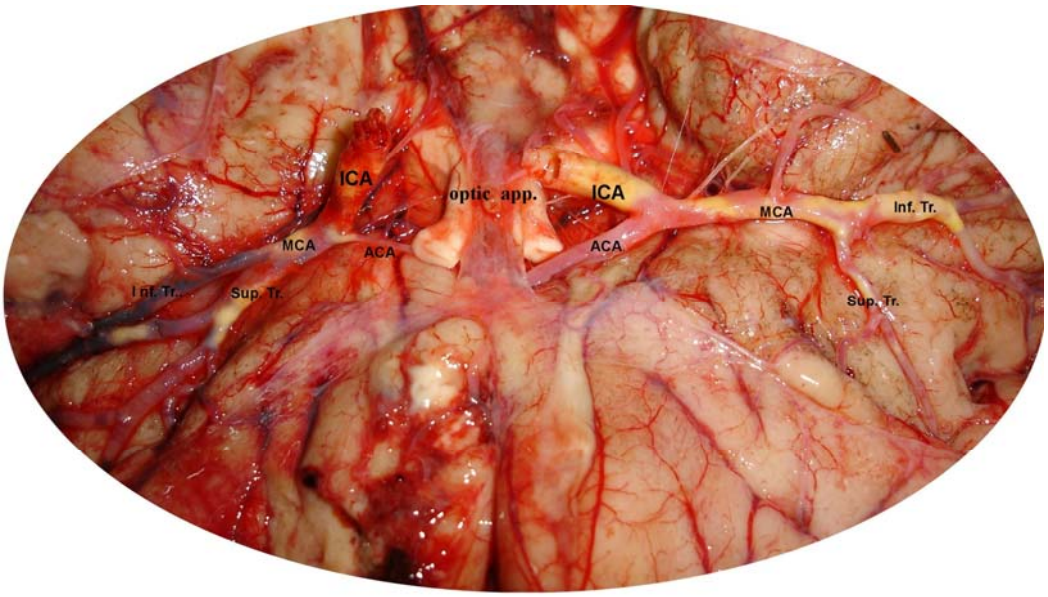



**Fig.8 : Variation in trunk dominance in same cadaver**

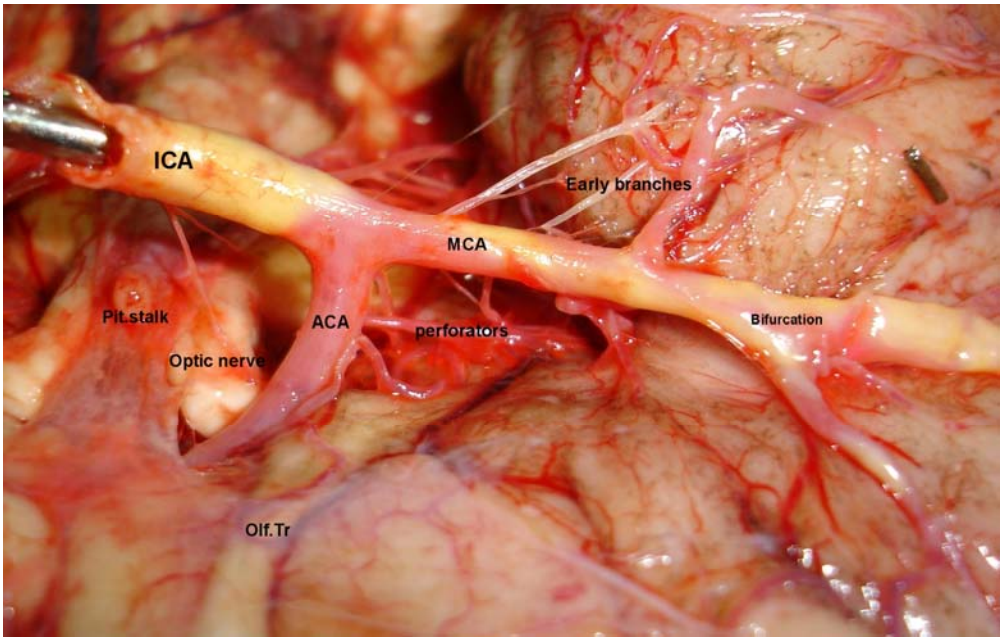



**Fig.9 : MCA With Perforators**

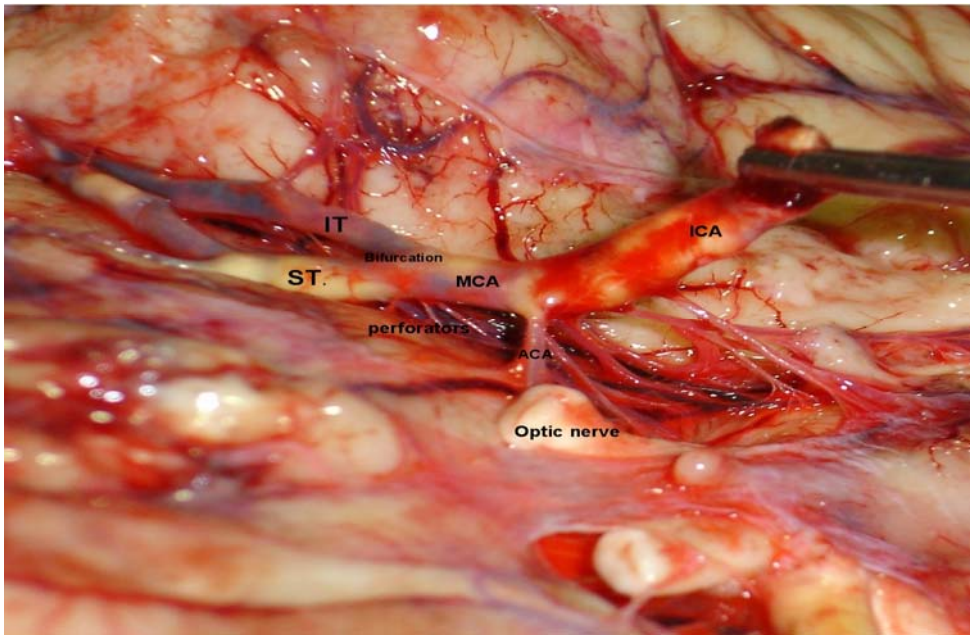



**Fig.10 : MCA With Perforators**

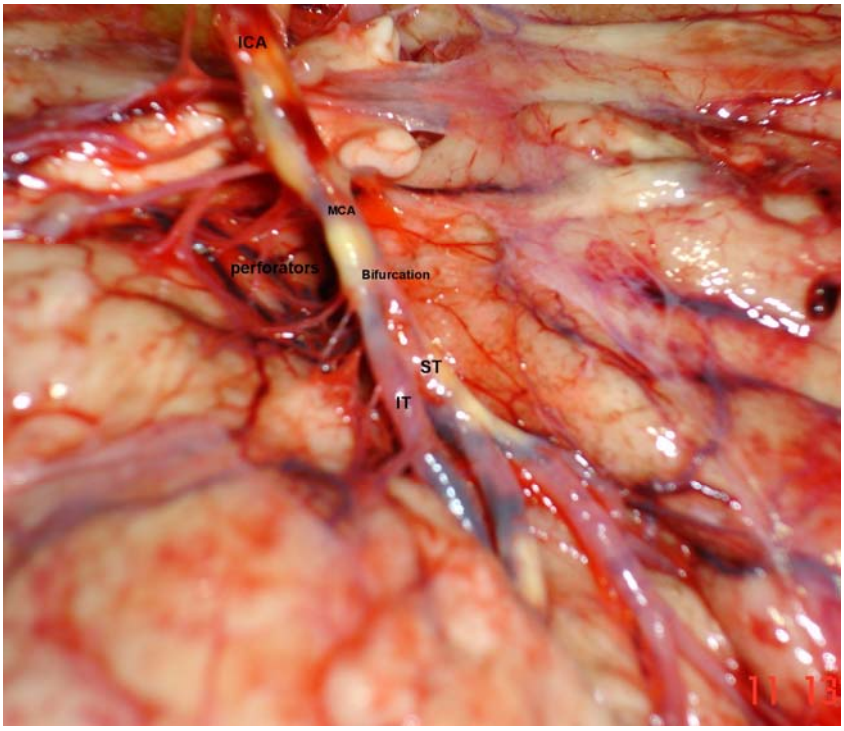



**Fig. 11 : MCA With Perforators**

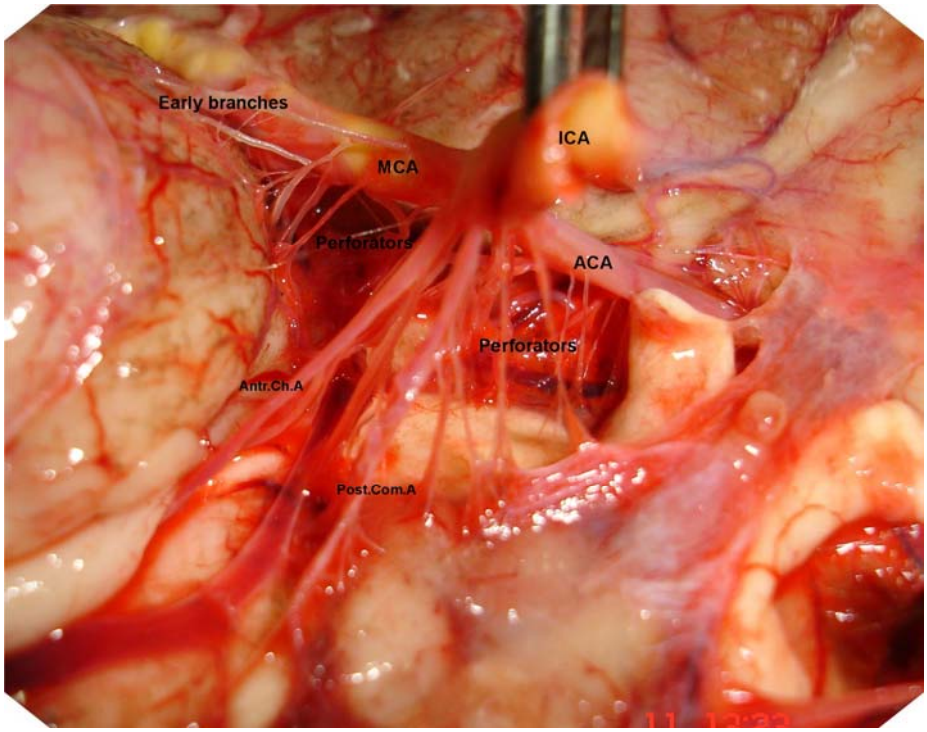



**Fig.12 : MCA With Perforators**

# RESULTS & ANALYSIS

The obtained data was analysed using descriptive statistics and student T-test.

**MCA outer diameter ($M_1$OD):**

The average outer diameter of MCA just distal to division was **3.1** mm.

The maximum outer diameter recorded was **4.5** mm.

The minimum outer diameter recorded was **2** mm.

**Table : 1**

**MCA outer diameter**

| | **Max.** | **Min.** | **Mean** | **S.D.** |
|---|---|---|---|---|
| $M_1$OD | 4.5mm | 2mm | 3.1 mm | 0.6024 |

**MCA cross sectional Area (M1CSA):**

MCA - Cross sectional area was calculated using the formula

$$M_1CSA = \pi \left( \frac{M_1\ OD}{2} \right)^2$$

The mean cross sectional area of middle cerebral artery was **7.6. mm$^2$**

**ACA OUTER DIAMETER (A1OD)**

The mean anterior cerebral artery outer diameter just distal to bifurcation was **1.542** mm.

The largest ACA was **2.5**mm in diameter.

The smallest ACA was **0.5** mm in diameter.

**Table : 2**

**ACA Outer Diameter**

| | **Max.** | **Min.** | **Mean** | **S.D.** |
|---|---|---|---|---|
| $A_1$OD | 2.5mm | 0.5mm | 1.542mm | 0.4248 |

On an average Anterior cerebral artery was **52.1%** of the size of Middle cerebral artery.

**ACA Cross Sectional area (AICSA):**

ACA cross sectional area was calculated using the formula

$$A_1CSA = \pi \left( \frac{A_1 OD}{2} \right)^2$$

The mean ACA cross sectional area was **2.998 mm$^2$**

**ICA outer diameter (ICOD):**

The mean outer diameter of internal carotid artery just proximal to bifurcation was **4.47** mm.

The largest IC outer diameter being **5.5**mm.

The smallest IC outer diameter being **3.5** mm.

**Table : 3**

**ICA Outer Diameter**

| | Max. | Min. | Mean | S.D. |
|---|---|---|---|---|
| ICOD | 5.5mm | 3.5mm | 4.47mm | 0.4497 |

**Internal carotid artery cross sectional area (ICCSA):**

ICA cross sectional area calculated using the formulae

$$\text{ICCSA} = \pi \left( \frac{ICOD}{2} \right)^2$$

The mean Internal carotid artery cross sectional area was **15.8113** $mm^2$.

**M1 segment length (MCAL)**

The average length of M1 segment was **16.88 mm.**

Shortest $M_1$ being - **12mm.**

Longest $M_1$ being - **26mm.**

**Table : 4**

**M1 segment length**

| | N | Minimum | Maximum | Mean | Std. Deviation |
|---|---|---|---|---|---|
| MCAL | 60 | 12 | 26 | 16.88 | 3.253 |

The average length of $M_1$ in bifurcating cases were **15.45mm.**

The average length of $M_1$ in trifurcating cases were **19.63 mm.**

The length in multiple dividing case was **22 mm.**

**Table : 5**

**$M_1$ Length in Variously dividing MCA**

| Furcation | N | Mean | Min | Max | S.D. |
|---|---|---|---|---|---|
| Bi | 40 | 15.45 | 12 | 19 | 1.934 |
| Tri | 19 | 19.63 | 14 | 26 | 3.547 |
| Multiple | 1 | 22.00 | 22 | 22 | - |
| Total | 60 | 16.88 | 12 | 26 | 2.253 |

The difference in $M_1$ length was found to be statistically significant using student T-test.

**Early Branches (EBR)**

Early branches are arteries supplying the cortical areas and have their origin directly from $M_1$ segment of middle cerebral artery.

It varies from one to four branches in each hemisphere.

All cases had early branch arteries.

43.8% had 1 early branch

41.7% had 2 early branches

11.7% had 3 early branches

3.3% had 4 early branches

**Table : 6**

**Early Branches**

| No. | Frequency | Percent |
|---|---|---|
| 1 | 26 | 48.8% |
| 2 | 25 | 41.7% |
| 3 | 7 | 11.7% |
| 4 | 2 | 3% |

In cases where there was more than 2 early branches, one or two of the vessels traversed towards the frontal lobe and they replaced the orbitofrontal cortical artery.

Out of the total 9 MCAs with more than 2 early branches, in 8 cases the early branch contributed to the Orbito frontal branch.

**Table : 7**

**Early branch vs Orbitofrontal artery cross tabulation.**

| Early Branch | Orbito frontal artery origin | | Total |
|---|---|---|---|
| No. | $M_1$ | ST | |
| **1** | | 26 | 26 |
| **2** | | 25 | 25 |
| **3** | 7 | | 7 |
| **4** | 1 | 1 | 2 |

**Accessory MCA(ACCMCA):**

Accessory MCA are arteries araising from ICA, ACA or AChA running into the sylvian fissure and progresses to supply a cortical area.

There were 4 accessory MCA in the present study constituting to 6.7% Three araising from ACA, and one arising from ICA.

**Table : 8**

**Accessory MCA**

| | Frequency | Percent |
|---|---|---|
| **Not present** | **56** | **93.3** |
| **Present** | **4** | **6.7** |
| **Total** | **60** | **100.0** |

**Perforating Arteries(PfA):**

Perforating arteries are small twigs of vessels araising from ACA, ICA, AChA, PcomA, and MCA that supply substantia innominata, lateral portion of the anterior commissure, most of putamen, globus pallidum, part of internal capsule, corona radiata and body and head of caudate nucleus.

Most perforators were from the infromedial surface of the middle cerebral artery.

Most perforators divided in a candelabra pattern before entering the anterior perforated substance.

Average number of perforators being **14.2 per MCA.**

The minimum number of perforators per MCA is **6**.

The maximum number of perforators per MCA is **22.**

**Table : 9**

**Perforators**

| | Number | Minimum | Maximum | Mean | S.D. |
|---|---|---|---|---|---|
| M1PP | 60 | 3 | 18 | 11.18 | 3.202 |
| M1DP | 60 | 0 | 7 | 3.02 | 1.479 |
| M1DP + M1PP | 60 | 6 | 22 | 14.2000 | 3.27186 |
| PP Percent | 60 | 30 | 100 | 22.0293 | 11.43779 |
| DP Percent | 60 | 0 | 70 | 77.9707 | 11.43779 |

Average number of perforators from proximal half of MCA is **11.18** which constituted to **77.9%**

Average number of perforators from distal half of MCA is **3.02** which constituted to **22.1%**

The MCA was divided into 2 groups as short and long taking the median 18mm as cut off point.

**Short MCA**

Proximal perforators constituted to **76.1%.**

Distal perforators constituted to **23.9 %.**

**Long MCA**

Proximal preforators constituted **81%** of perforators

Distal perfortators constituted **19%** of perforators.

**Table : 10**

**MCA Length vs Perforators**

| MCA | | Distal perforators | Proximal perforators |
|---|---|---|---|
| Short (< 18) | N | 37 | 37 |
| | Mean % | 23.8832 | 76.1168 |
| | Minimum % | 6.25 | 30.00 |
| | Maximum % | 70.00 | 93.75 |
| | Std. Deviation | 11.40468 | 11.40468 |
| Long (>=18) | N | 23 | 23 |
| | Mean % | 19.0471 | 80.9529 |
| | Minimum % | 0 | 57.14 |
| | Maximum % | 42.86 | 100.00 |
| | Std. Deviation | 11.08737 | 11.08737 |

The perforators were uniformly distributed along the MCA and there was no significant difference between short and long ones.

Few perforators also arose from $M_2$, anterior temporal and orbitofrontal arteries.

Numerous perforators arose from $M_2$ segment supplying insular cortex all along their course.

**Division of MCA**

MCA - Bifurcated into superior and inferior trunk in 40 cases (66.7%)

On the right side 21 bifurcations were noted, while on the left 19 were observed.

MCA - Trifurcated into superior, middle and inferior trunks in 19 cases (31.7%)

On the right side 8 trifurcated while on the left 11 cases were noted.

One MCA divided into multiple trunks.

**Table : 11**

**Furcation**

| | **Frequency** | **Percent** |
|---|---|---|
| Bi | 40 | 66.7 |
| Tri | 19 | 31.7 |
| Multiple | 1 | 1.7 |
| Total | 60 | 100.0 |

In most cases there were symmetry between two sides with regards to pattern of division.

**Table : 12**

**Side vs Furcation Crosstabulation.**

| **Side** | **Furcation** | | | **Total** |
|---|---|---|---|---|
| | **Bi** | **Tri** | **Multiple** | |
| Right | 21 | 8 | 1 | 30 |
| Left | 19 | 11 | | 30 |
| Total | 40 | 19 | 1 | 60 |

Only in 2 cases, MCA bifurcated on the right side and trifurcated on the left side.

In one case MCA divided into multiple branches on the right side and trifurcated on the left side.

**DOMINANCE**

- In trifurcating and multiply dividing MCAs all trunks were more or less equal in size.
- In bifurcating MCA, most cases showed dominance of one trunk.
- Out of 40 bifrucating MCAs
    - Superior trunk was dominant in **35%** of cases (14 MCA).
    - Inferior trunk was dominant in **52.5%** of cases (21 MCA).

**Table : 13**

**Dominance**

| Dominance | Frequency | Percent |
|---|---|---|
| ST | 14 | 35 |
| IT | 21 | 52.5 |
| Equal | 5 | 12.5 |
| Total | 40 | 100 |

**Table : 14**

**Cortical artery and its origin**

| | ST | IT | MT | M1 | Total |
|---|---|---|---|---|---|
| Orbitofrontal | 52 | | | 8 | 60 |
| Prefrontal | 59 | | | 1 | 60 |
| Pre Central | 59 | | 1 | | 60 |
| Central | 49 | | 11 | | 60 |
| Antr. Pareital | 35 | 7 | 17 | | 59 |
| Post.Pareital | 17 | 24 | 19 | | 60 |
| Angular | 3 | 38 | 12 | | 53 |
| Temporo occiptial | | 49 | 6 | | 55 |
| Post.Temporal | | 60 | | | 60 |
| Mid. Temporal | | 56 | | 4 | 60 |

The origin of the cortical arteries are variable to an extent of unpredictability.

The pareitooccipital and angular arteries were infrequently absent. When one is absent the other becomes comparatively larger to cover the additional area.

**Orbito Frontal Artery**

Orbito Frontal artery originated in 13.3% from M1 as early branch.

In 86.7% it was from Superior trunk.

**Table : 15**

**Orbito Frontal Artery**

| | Frequency | Percent |
|---|---|---|
| M1 | 8 | 13.3 |
| ST | 52 | 86.7 |
| Total | 60 | 100 |

**Prefrontal Artery**

Pre Frontal artery originated in 1.7% from M1 as early branch. In 98.3% it was from Superior trunk.

**Table : 16**

**Prefrontal Artery**

| | Frequency | Percent |
|---|---|---|
| M1 | 1 | 1.7 |
| ST | 59 | 98.3 |
| Total | 60 | 100 |

**Precentral Artery**

Precentral artery originated in 1.7% from middle trunk and in 98.3% it was from Superior trunk.

**Table : 17**

**Precentral Artery**

| | Frequency | Percent |
|---|---|---|
| MT | 1 | 1.7 |
| ST | 59 | 98.3 |
| Total | 60 | 100 |

**Central Artery**

Central artery originated in 18.3% from middle trunk. In 81.7% it was from Superior trunk.

**Table : 18**

**Central Artery**

| | Frequency | Percent |
|---|---|---|
| MT | 11 | 18.3 |
| ST | 49 | 81.7 |
| Total | 60 | 100 |

**Anteriorpareital Artery**

Anterior Pareital artery originated in 11.7% from Inferior Trunk

In 28.3% it was from middle trunk.

In 58.3% it originated from superior trunk.

**Table : 19**

**Anteriorpareital Artery**

| | Frequency | Percent |
|---|---|---|
| IT | 7 | 11.7 |
| MT | 17 | 28.3 |
| ST | 35 | 58.3 |
| Total | 60 | 100.0 |

**Posterior Pareital Artery**

Posterior parietal artery originated in 40% from inferior trunk.

In 31.7% it was from middle trunk.

In 28.3% it was from superior trunk.

**Table : 20**

**Posterior Pareital Artery**

| | Frequency | Percent |
|---|---|---|
| IT | 24 | 40.00 |
| MT | 19 | 31.7 |
| ST | 17 | 28.3 |
| Total | 60 | 100.0 |

**Angular Artery**

Angular artery was absent in 11.7% of cases.

In 63.3% it originated from inferior trunk.

In 20% of MCA it originated from middle trunk.

Only in 5% of cases it was from superior trunk.

**Table : 21**

**Angular Artery**

| | Frequency | Percent |
|---|---|---|
| Absence | 7 | 11.7 |
| IT | 38 | 63.3 |
| MT | 12 | 20.0 |
| ST | 3 | 5.0 |
| Total | 60 | 100.0 |

**Temporo occipital Artery**

Temporo occipital artery originated from inferior trunk in 81.7%.

In 10% of cases in was from middle trunk.

It was absent in 8.3% of cases.

**Table : 22**

**Temporo occipital Artery**

| | Frequency | Percent |
|---|---|---|
| Absence | 5 | 8.3 |
| IT | 49 | 81.7 |
| MT | 6 | 10.0 |
| Total | 60 | 100.0 |

**Posterior Temporal Artery**

All the posterior temporal arteries were from the inferior trunk.

**Table : 23**

**Posteriortemporal Artery**

| | Frequency | Percent |
|---|---|---|
| IT | 60 | 100 |

**Middle Temporal Artery**

In 6.7% of cases middle temporal artery originated from $M_1$ segment as early branch.

In 93.3% it originated from inferior trunk

**Table : 24**

**Middletemporal Artery**

| | Frequency | Percent |
|---|---|---|
| IT | 56 | 93.3 |
| M1 | 4 | 6.7 |
| Total | 60 | 100.0 |

**Largest of Cortical Arteries**

- The angular or the temporo occipital artery was the largest of the cortical arteries. When one is absent other dominated to supply the additional area.

- The angular artery was dominant in 63.3% of cases.

- The temporo occipital artery was dominant in 36.7% of cases.

**Table : 25**

**Largest of Cortical Artery**

| | **Frequency** | **Percent** |
|---|---|---|
| LCPO | 22 | 36.7 |
| LCA | 38 | 63.3 |
| Total | 60 | 100.0 |

**Number of cortical arteries from each trunk**

In bifurcating cases - from the superior trunk 5 branches arose while from the inferior trunk 4.3 branches arose on an average.

In trifurcating MCAs, on an average 3.7 branches were from the superior trunk, 2.9 branches were from the middle trunk and 3 branches were from the inferior trunk.

**Table : 26**

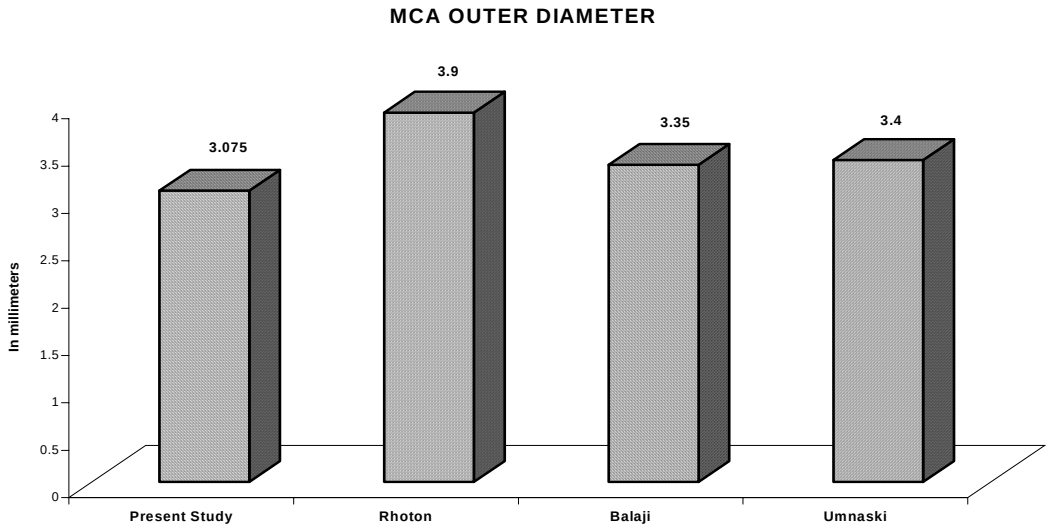
**Number of Cortical Arteries from each trunk**

| Furcation | | ST | MT | IT |
|---|---|---|---|---|
| Bifurcation | N | 40 | 40 | 40 |
| | Mean | 5.1 | 0 | 4.3 |
| | Minimum | 3 | 0 | 2 |
| | Maximum | 7 | 0 | 6 |
| | Std. Deviation | 0.96 | 0 | 1.1 |
| Trifurcation | N | 19 | 19 | 19 |
| | Mean | 3.7 | 2.9 | 3 |
| | Minimum | 2 | 0 | 2 |
| | Maximum | 7 | 5 | 6 |
| | Std. Deviation | 1.1 | 1.5 | 1.1 |

# COMPARISON OF DATA

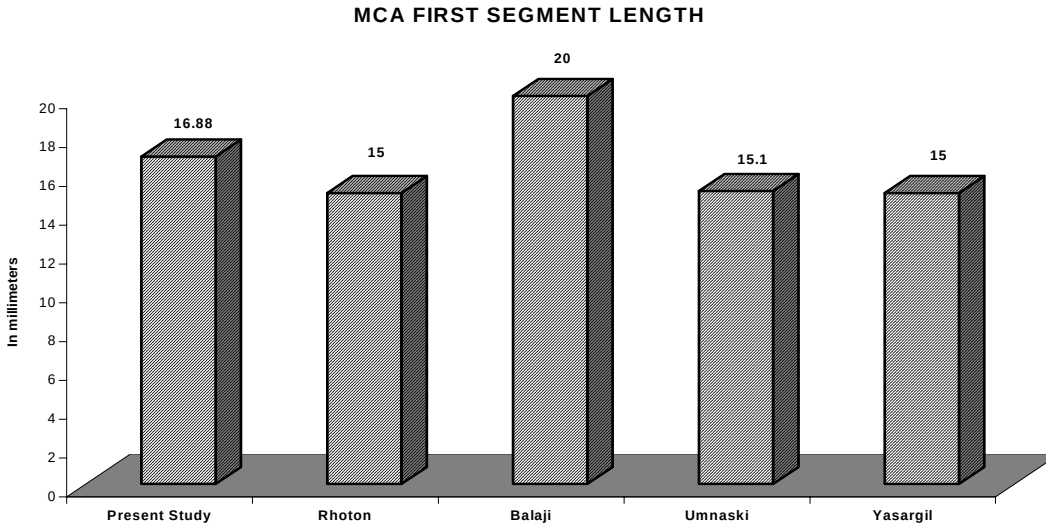
The present study on the microsurgical anatomy of middle cerebral artery in our population, had some significant difference when compared with similar studies in literature done on western population and other regions of Indian population.

## 1. MCA Outer Diameter




MCA outer diameter is comparatively smaller in the present study compared to western population. The difference is minimal when compared with the study by Balaji pai.

## 2. MCA Length

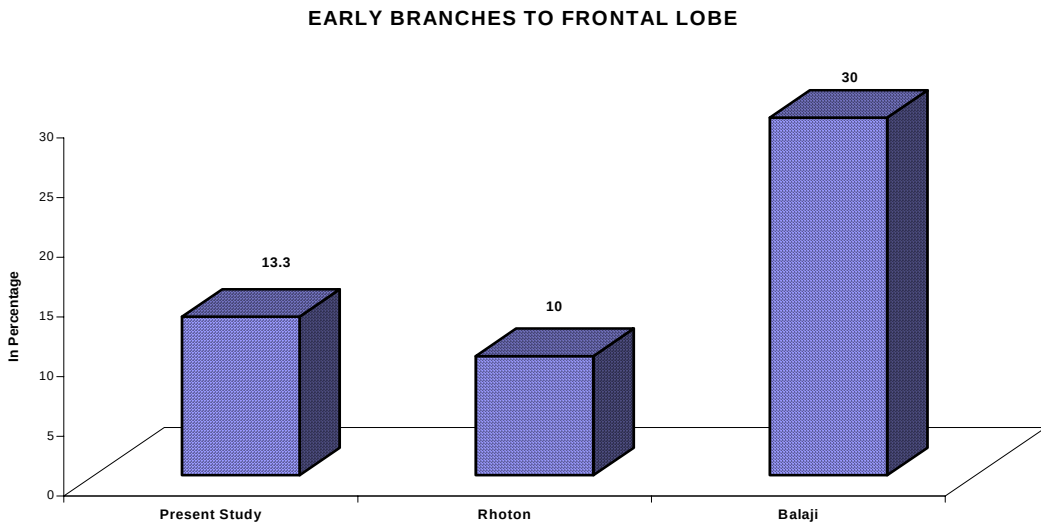



The average MCA length is comparatively longer by few millimeters than the western studies.

## 3. MCA CSA

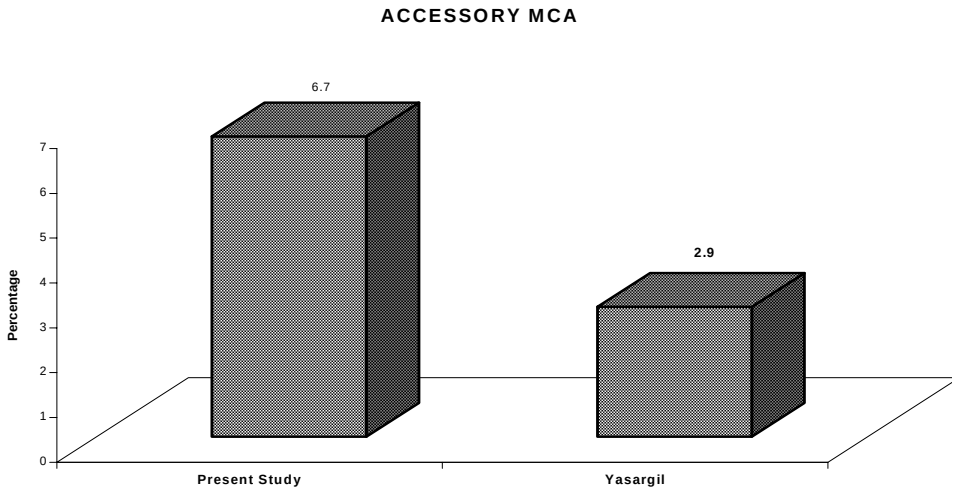
So far no other study has analysed the cross section area of MCA.

## 4. Early Branches to Frontal lobe



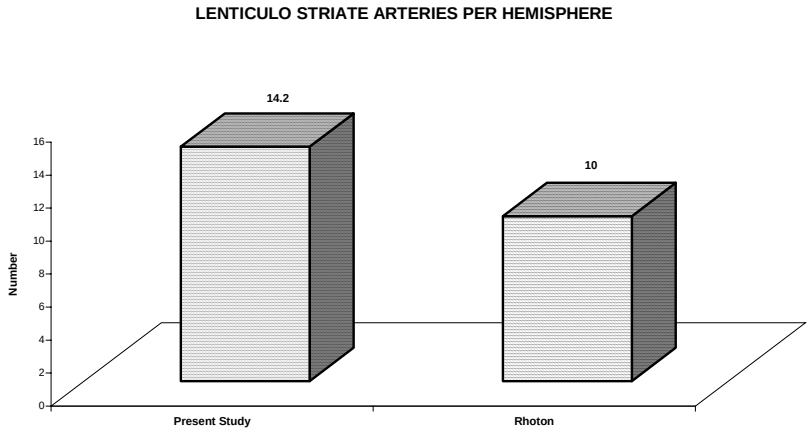

The Early branch to frontal lobe (12.3%) is similar to the one published by Rhoton (10%). Balaji Pai has reported 30% incidence.

## 5. Accessory Middle Cerebral Artery



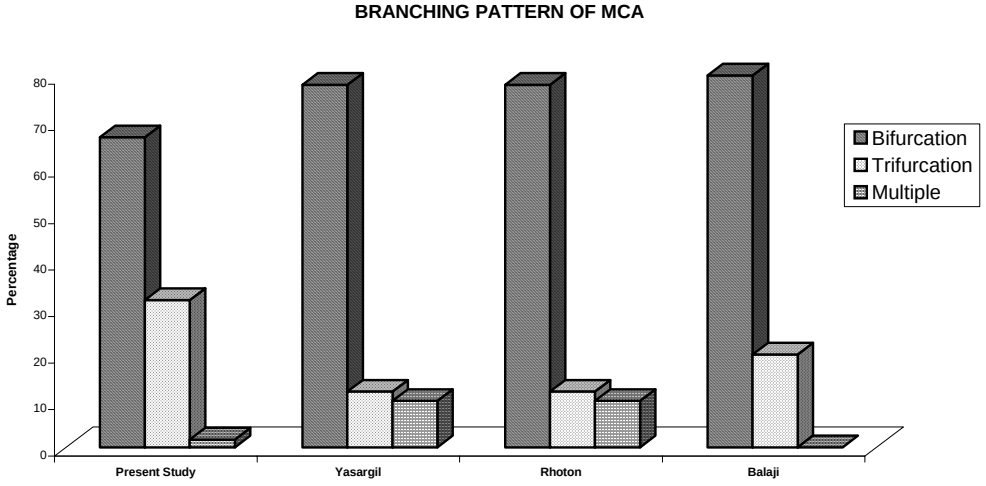

Accessory MCA occured in 6.7% of cases but Yasargil has recorded only 2.9%.

## 6. Lenticulostriate Arteries



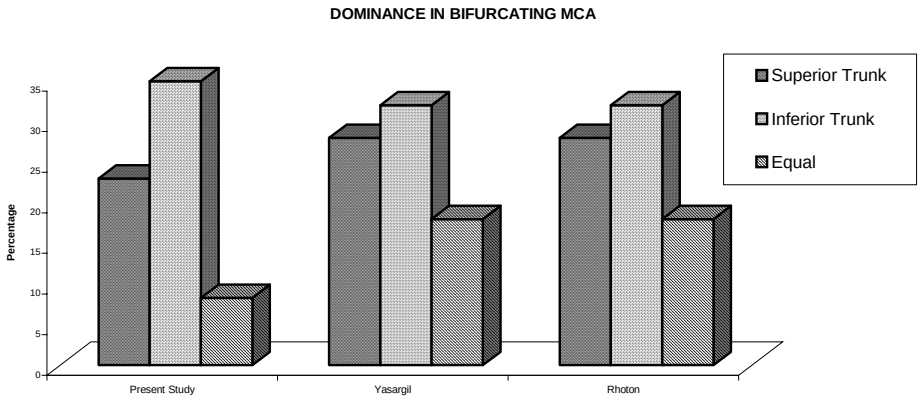

On an average 14.2 Lenticulostriate arteries were present per hemisphere in the present study. Rhoton has recorded 10 per hemisphere.

## 7. Branching Pattern of MCA



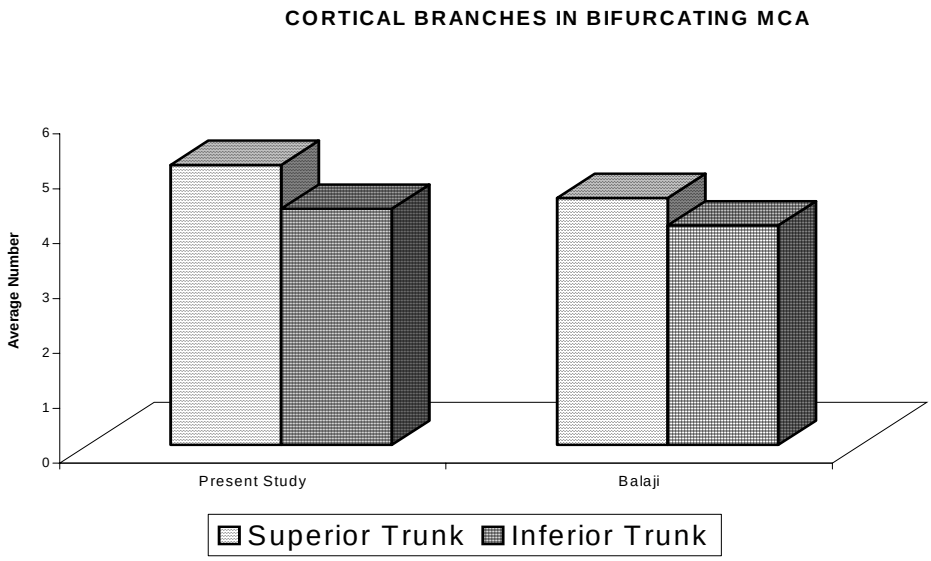

In the present study much lower number of bifurcations (66.7%) and higher number of trifurcations (31.7%) have been recorded compared to other studies.

## 8. Dominance



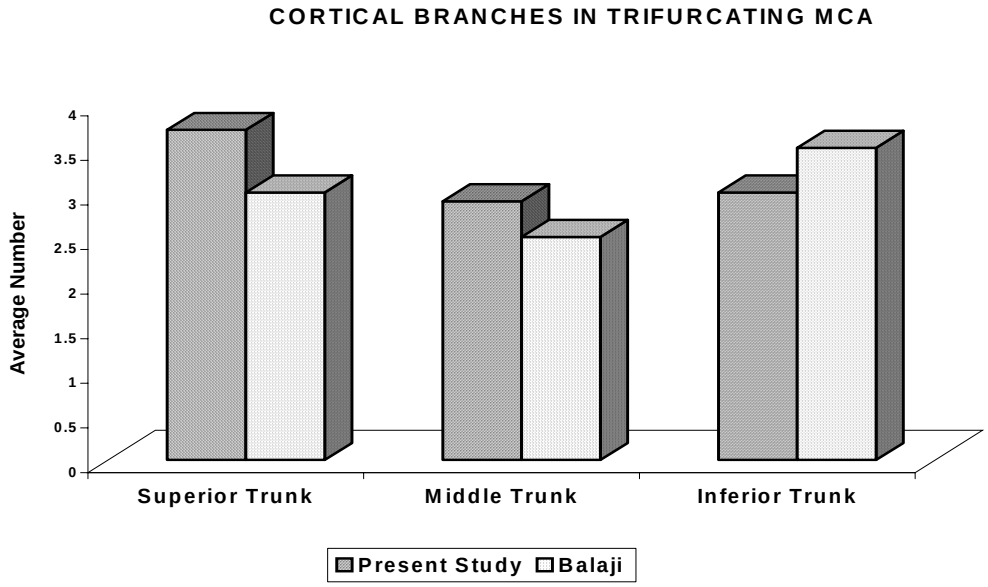

The findings in the present study is comparable with other studies.

## 9. Cortical Branches in Bifurcating MCA




There is no gross difference in the number of cortical branches from each trunk as compared to the study by Balaji pai.

## 10. Cortical Branches in Trifurcating MCA




There is a minimal difference in the number of cortical arteries arising from each trunk of trifurcating MCA as compared to Balaji Pai study.

# DISCUSSION

Based on the observations of the present study, the significance are discussed on

1. Anatomical perspective
2. Pathophysiological perspective
3. Neurosurgical perspective

**Anatomical Perspectives**

- Middle cerebral arery is a direct branch of internal carotid artery as it is in line in all cases, where as Anterior cerebral artery araises at an angle varying from 30-100$^{o}$ in this study . This finding is in concurrence with studies by Rhoton and Yasargil.

- Middle cerebral atery is a larger branch of internal carotid artery, on an average double the size of anterior cerebral artery.

- The combined cross sectional area of MCA and ACA was always smaller than the cross sectional area of ICA. The cross sectional area has not been analysed by any of the previous studies.

- The average length of MCA was **16.88**mm, being shorter in bifurcating MCAs (15.45mm) and longer in trifurcating MCAs (19.63mm).

- Early branches (superolateral arteries) are seen in all cases. Mostly arising as 2 branches forming anterior temporal artery and temporal polar artery, while in some cases it had a common origin later dividing into 2 branches.

- In 13% of hemispheres early branch replaced orbitofrontal artery. No previous study has quoted this incidence.

- In 1.7% of hemispheres early branch replaced prefrontal artery, that is in only one hemisphere. This is a rare finding.

- In 6.6% of hemispheres early branch replaced middle temporal artery.

- Accessory MCA though seen in 6.7% of cases, it did not replace any cortical artery. Accessory MCA was not consistant in location.

- Perforators were seen from infromedial aspect dividing in candelabra pattern before entering the anterior perforated substance as has been described in other studies, but the average number was larger than that recorded in western studies.

- Irrespective of the length of MCA, perforators were uniformly distributed and in some cases arose from $M_2$ and proximal segments of frontal and temporal cortical arteries.

- There were numerous perforators from the $M_2$ segment of MCA entering the insular cortex.

- 66.7% of MCA bifurcated, 31.7% trifurcated, though in most cases there was a symmetry between the two sides, it was not to be taken for granted, as the difference between two sides did happen.

- The dominant trunk was more in line with the parent vessel while the non-dominant trunk took off at an angle.

- Beyond bifurcation branching of vessels did not have any definite pattern. Most branching occured over insula, took $180^{o}$ at limiting sulcus to run over the opercula, then took another $180^{o}$ turn to run over the cerebral cortex.

- Broca's area and motor area were consistently supplied by superior trunk, even if non dominant.

- Wernicke's area was supplied by either the inferior or the middle trunk.

- The angular or temporo occipital artery was the largest of the cortical arteries. In case where one is absent, other dominated.

**Pathophysiological perspectives**

- Embolic stroke, the commonest cause of stroke and secondary deposits tend to affect the MCA territory as it is more in line with ICA and larger in calibre.

- A fall in BP may affect ACA territory frequently as it is more at an angle.

- Faciobrachial stroke, with motor aphasia can occur if the superior trunk is involved in thrombosis.

- Pure sensory aphasia in the absence of hemiplegia occur if the inferior or middle trunk is occluded.

- Involvement of individual cortical branch, may produce symptoms pertaining to the area supplied. Due to the variability in size and area supplied, it is difficult to predict the exact branch. Even with angiography, identification of block in these vessels may be difficult.

**Neurosurgical Perspectives**

- The MCA is mostly uniform in size, but the gross variation in size of the ACA - may pose a difficulty in locating the division, intra operatively. So a detailed angiographic evaluation is mandatory preoperatively.

- Irrespective of the length of MCA, it is not freely mobile, as the tie of perforators hampered their mobility.

- The early branches from suprolateral aspect are to be negotiated before reaching the MCA aneurysms, they are to be preserved as they supplied cortical areas without any vascular reinforcement from other cortical arteries.

- Accessory MCA never replaced any cortical artery, so they may be dispensed in pathology involving them.

- The dissection is to be kept to a minimum on infromedial aspect of the middle cerebral artery as there is a high risk of damage to the tiny perforating vessels.

- As the perforators are uniformly distributed all along the middle cerebral artery temporary clipping is to be avoided. If mandatory, temporary clips have to be applied as distal as possible to avoid ischemia to the areas supplied by these perforators.

- The perforating vessels to the insula are present all along the $M_2$ segment and they have to be handled carefully. Damage to a large perforator may result in limb weakness as they may supply the corona radiata or internal capsule.

- Insular cortical incisions are made anywhere depending upon the deeper area to be reached but no area is safe as all the $M_2$ vessels give perforators to the insula, extreme care must be taken to prevent the mobilization of vessels from its original position.

- In cases of MCA occlusion, the most preferred vessel for anastamosis (STMC bypass) would be angular or temporo occipital artery, as they are the most distal as well as the largest of the cortical arteries.

# CONCLUSION

- MCA is the larger and more direct branch of ICA, enabling emboli to enter it, resulting in common MCA territory stroke, secondary deposits and abscess formation.
- $M_1$ segment is shorter in bifurcating and longer in trifurcating vessels, but their mobility was largely dependent on the length and tortuosity of the infromedial perforators.
- Accessory MCA are rare, and do not replace any cortical vessel, so may be dispensed if mandatory.
- Perforators arises uniformly from infromedial aspect of MCA, so dissection must be kept to a minimum, and application of temporary clips must be as distal as possible.
- The pattern of MCA division must be studied in detail preoperatively with angiography as they are the commonest site of MCA aneurysm and it varies between sides.
- Distal branching of MCA did not have any definite pattern.
- Faciobrachial weakness with or without broca's aphasia occurs due to the involvement of superior trunk.
- No area over insula is safe for insular cortical incision. If mandatory it has to be made without mobilizing the vessels coursing over the insula.
- In MCA occlusion the angular or temporo occipital artery is the preferred cortical vessel for anastamosis.

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# OBSERVATION CHART

Microsurgical anatomy of MCA.

Side: Age: Sex:

OBSERVATIONS:

1. ICA – OD:
2. MCA-OD:
3. ACA-OD:
4. MCA- Length
5. Early branches:
6. Accessory MCA:
7. Perforators:

   M1 Perforators:
   Proximal:
   Distal:

   M2 Perforators:

   Proximal Frontal and Temporal:

8. M1 division:

| | Bifurcation | Trifurcation | Multiple |
|---|---|---|---|
| Branching pattern | | | |

9. Dominant trunk:

10. Cortical branches:

| | Orbito frontal | pre frontal | pre central | central | Anterior pareital | Posterior pareital | Middle temporal | Posterior temporal | Temporo occipital | Ang ular |
|---|---|---|---|---|---|---|---|---|---|---|
| Superior | | | | | | | | | | |
| Middle | | | | | | | | | | |
| Inferior | | | | | | | | | | |

11. Largest of Cortical Artery